# THERMAL CONDUCTIVITY OF TILE AND THEIR VALUE AS FIREPROOFING MATERIAL

BY

S. W. ANDERSON

J. F. CHAMBERLIN

ARMOUR INSTITUTE OF TECHNOLOGY

1915

A THESIS

Presented By

S. W. Anderson

and

J. F. Chamberlin

to the

PRESIDENT AND FACULTY

of

ARMOUR INSTITUTE OF TECHNOLOGY

For the Degree

of

BACHELOR OF SCIENCE IN FIRE PROTECTION ENGINEERING

Having Completed the Prescribed

Course of Study in

FIRE PROTECTION ENGINEERING

1915

.....................................
Professor of Fire Protection Engineering

.....................................
Dean of Engineering Studies

Date..............

.....................................
Dean of Cultural Studies

# The Thermal Conductivity of Various Forms of Tile and Their Value as Fireproofing Materials

# THE THERMAL CONDUCTIVITY OF VARIOUS FORMS OF TILE AND THEIR VALUE AS FIREPROOFING MATERIALS

## Index to Chapters

## LIST OF SKETCHES AND PHOTOGRAPHS

### SKETCHES



### PHOTOGRAPHS

## LIST OF CURVES

# C H A P T E R I.

## INTRODUCTION

# INTRODUCTION

The thesis presented herein can be said to be only the beginning of research work on this particular subject because the field covered is practically without limit, but the method formulated and adopted by the writers is applicable to any of the many forms of tile and other fireproofing materials used in building construction at the present time. The problem presented for solution was mainly the design of apparatus which would satisfactorily and accurately measure the heat transmitted through fireproofing materials, followed by the application of the apparatus to as many forms of tile as our limited time would permit.

As no apparatus, known to the writers, had previously been designed for this particular purpose, the attack on the problem was purely experimental, and the design, as first adopted, demonstrated conclusively where the improvements were necessary. Accordingly, the apparatus was rebuilt, and in the succeeding tests gave satisfactory results.

The application of the apparatus has been made on only four samples, but the samples were chosen with the idea of compiling data on a few varied forms, and although no definite conclusions can be drawn from the information obtained, yet enough can be gleaned to give a few concrete ideas as to their relative value.

The writers wish to extend their thanks to Mr. Johnson, Vice-President of the National Fireproofing Company, for the samples that were tested, and to the Engineers of the Underwriters' Laboratories, who extended valuable assistance at various times.

# INTRODUCTION.

The thesis presented herein can be said to be only the beginning of research work on this particular subject because the field covered is practically without limit, but the [illegible] the writers is applicable to any of the many forms of [illegible] fire proofing materials used in building construction at the present time. The problem presented for solution was [illegible] which would satisfactorily and accurately measure [illegible] transmitted through fireproofing material, followed by [illegible] of the apparatus as many forms of [illegible] as our limited time would permit.

[illegible] no paper [illegible] known to the writers [illegible] designed for this particular purpose, [illegible] original, and the design, as first [illegible] where the improvements were necessary. [illegible], the apparatus was rebuilt, and [illegible] satisfactory results.

The application of the apparatus [illegible] samples, but [illegible] a few varied forms, [illegible] no definite conclusions [illegible] from the information [illegible], but enough [illegible] concrete ideas as to their relative value.

The writers wish to extend [illegible] thanks [illegible] of the [illegible] were tested, and [illegible] extended valuable [illegible] at various times.

# C H A P T E R I I

## DESCRIPTION OF APPARATUS USED IN THE THESIS

A. Furnace and Furnace Panels

B. Pyrometers and Thermometers

C. Calorimeter, etc.

## FURNACE AND FURNACE PANELS.

**FURNACE CONSTRUCTION** The furnace is built of heavy fire brick, laid in fire-clay motar and is shown by a photograph in Chapter VI. The outer face is made of pressed brick, laid in ordinary plaster motar. At the four vertical edges of the furnace, heavy three inch angles are provided, the two front and the two rear being connected at both bottom and top by heavy bolts. The entire setting rests on heavy steel framework which in turn is mounted on heavy casters, which permit and facilitate movement of the furnace. For the escape of burned gases, eight openings are provided in the arch, averaging in dimensions 3-3/8 inches by 4 inches. At each side of the furnace four openings, each 4 inches by 4 inches, are provided for the gas burners. Two small holes, one on each side, are provided for the insertion of furnace pyrometers.

**HEATING** The furnace is heated by eight burners, four on each side, each burner being made of three-fourths inch pipe, with controlling valve attached, connected to a one and three-quarter inch pipe, connected to the gas supply main. Air is supplied from an air blower to all burners through two and one-half inch pipes, with controlling valve attached at all burners. At the bottom burner on each side a small pilot light is provided. The flames of all the burners impinge on the middle of the back of the furnace and the heat is then reflected to the middle of the test wall.

**PANEL FRAME-WORK** For the testing of the samples, a test wall in the form of a steel frame, divided into three panels, was constructed. Under the middle panel, four casters were provided, which permitted movement of the whole frame. The middle panel was filled solid with large gypsum blocks and was used as a blank wall before the test panel was moved into place. The two end panels were used for mounting the test samples. At the four corners of each test panel holes were tapped and drilled for one-half inch pipes, which served as supports for adjustable frame-work of the calorimeter.

# PYROMETERS AND THERMOMETERS

PYROMETERS The pyrometers used in the tests that follow, consisted of four platinum iridium, and three copper constantan couples. The platinum couples consisted of two wires which were fused together at one end and soldered to their leads at the other end. The fused end was designated as the hot junction and the soldered end as the cold junction. In the case of the copper couples the hot junction was fused together but at the cold junctions the wires and the leads were placed in a glass tube containing mercury. In actual tests, the couples were placed in clay tubing at the hot junction end, and in asbestos rope, from the clay tubing to the cold junction, in order to protect the wires from being crossed or coming into contact with any metal.

CALIBRATION In calibrating, the metal used was heated above its melting point, and the hot junction placed in the center of the molten metal, while the cold junction was placed in small glass tubes in ice. The leads attached to the couple extended to the particular galvanometer used. The metal was then allowed to cool while readings of the galvanometer were taken at intervals of every fifteen seconds until solidification occurred. A curve was then plotted in every case between galvanometer readings and time, and the freezing point taken as shown where the galvanometer readings were constant. Thecurve plotted showed a decided straight line at the freezing point in every case. The freezing points of the metals used were taken from the Government Reports on the freezing point of pure metals. Knowing the melting points of the metals used and the corresponding galvanometer readings, a calibration curve was drawn for each couple, plotting temperatures as ordinates and millivolts as abscissa. The calibration data will be found in Chapter IV and the curves in Chapter V.

THERMOMETERS The thermometers used in measuring the temperature of water at entrance and exit in the calorimeter and annular ring were obtained from the physics department. All were calibrated to a standard thermometer, and all readings given in the test record are corrected.

## THE CALORIMETER

**CHOICE OF DESIGN** The design of apparatus for the measurement of the heat transmitted through the various forms of tile, presented a problem which was more difficult of solution than the accompanying design would seem to indicate. It was only after careful analysis of the conditions that were to be met with in the different tests that the particular design was chosen. Subsequently, it was found necessary to make some changes that would more perfectly meet the requirements. This design was chosen because it presented the most feasible means of obtaining results that would be accurate.

**THE DESIGN** The design of the calorimeter embodied the idea of having a thin layer of water pass through a definite channel from A to B as shown in the sketch. On account of the thinness of the layer of water, a uniform temperature prevailed throughout. The product of the difference in temperature at entrance and exit, and the weight of water represents the amount of heat absorbed by the water during passage. The design of the calorimeter is shown in Sketch No. I. It was made of #28 B and S gauge copper sheet with all joints carefully and tightly soldered. Short pieces of copper tubing were used in providing passage ways for the pyrometers. Short brass nipples three-eighths inches in diameter were well soldered at entrance and exit for the attachment of the supply and discharge pipes.

**THE ORIGINAL APPARATUS** The insulation originally provided for the calorimeter, consisted of three layers of cork arranged as in Illustration No. II. The layer flush with the face of the calorimeter was of one-half inch finely ground and pressed cork, in the center of which a recess large enough for the insertion of the calorimeter was carefully turned. In back of this was provided two layers of cork, each layer two inches in thickness, of coarse heavy stock and pressed with natural cork oil. The three layers of insulation were held in position by a galvanized iron vessel, the edges of which did not quite extend to the outer edge of the thin layer of cork. Short brass screws were set through the vessel into this layer. As a tight fit was provided for the other layers, the entire insulation was held in the vessel rigidly. A circle eight inches in diameter was cut in the back of the vessel, thereby exposing the back layer of the insulation. This was considered necessary, in order that no heat could be conducted from the vessel to the water pipes, which pass through the cork insulation, from the calorimeter to the fittings provided for the measurement of the temperatures of the water at entrance and exit. The fittings, placed as close as was practicable to the back of the vessel, consisted of an elbow and a tee insulated by a mold of Kiesel Guhr and gypsum. For the insertion of the pyrometers, holes were drilled through the cork in coincidence with the holes in the calorimeter, so that the pyrometers

CRITICAL [illegible] The design of [illegible] the heat transfer [illegible] of tile [illegible]
difficult of solution [illegible] the complexity [illegible] involved. It was only after careful [illegible] that were to be dealt with in the difficulties [illegible] design was chosen. Subsequently, it [illegible] make some changes that would [illegible]. This design [illegible] because [illegible] of obtaining results that would be [illegible].

THE DESIGN [illegible] design of the calorimeter [illegible] of having a thin layer [illegible] definite [illegible] from [illegible] the thickness of the layer of [illegible] throughout. The [illegible] tree and salt, and the water [illegible] not absorbed by the water [illegible] calorimeter [illegible] in sketch [illegible] gauge copper [illegible] joints [illegible] tight [illegible]. Short pieces of copper tubing were used [illegible] for the pyrometers. [illegible] were well soldered [illegible] of the supply and discharge pipes.

THE RIGIDITY [illegible] THE [illegible] [illegible] order [illegible] calorimeter [illegible] the face of the calorimeter [illegible] grease cork, in the center of which [illegible] insertion of the [illegible] was provided [illegible] piece of cork [illegible] of coarse [illegible]. layers of insulation were held [illegible] vessel, the edges [illegible] the thin layer [illegible] vessel into this layer [illegible] layers, the entire insulation was held [illegible] eight inches in diameter was cut in [illegible] exposing the next layer of the insulation [illegible] necessary, in order that [illegible] the water pipes, which [illegible] outlet water to [illegible] temperatures of the water [illegible] as close as [illegible] floor and [illegible] insulation [illegible] the insertion of the pyrometers, holes [illegible] in coincidence with the holes [illegible]

had a straight passage through the insulation and calorimeter to the sample form.

INSULATION FAILURE — During the test, which is not recorded in these contents, the cork adjacent to the tested sample was burned out, and new means of insulation had to be devised. The burning of this insulation spoiled all results of the test, but gave valuable information as to the proper means of insulation and the form it should take.

ANNULAR RING — The method of insulation decided upon was two-fold in its application and provided a means of a more thorough insulation than that used in the first test. An annular ring was constructed of the same material as the calorimeter and is shown in illustration III. This was placed around the calorimeter with one-eighth inch clearance. At one side, the ring was divided with a copper strip, and water supply pipes were placed above and below this division wall, to insure the ring being full at all times. The discharge pipe was placed on the opposite side. Fittings for the measurement of the temperature of the entrance and exit water were provided similar to those on the calorimeter. At the outer edge of the annular ring a strip of copper ribbon was placed, serving as an adjunct in dissipating the heat away from the insulation.

RESULTS OBTAINED — The addition of the annular ring as a means of insulation for the calorimeter accomplished two results:

1. It protected insulation in back of the calorimeter and the ring from destruction;

2. It made a perfect insulation on the outside edges of the calorimeter.

The first of these results is obvious, because the entire face exposed to the heated sample was thoroughly cooled by the water passing through the calorimeter and the ring, and therefore sufficient heat could not be transmitted to the insulation to cause it to be destroyed. The second was accomplished by creating aperfect heat balance between the calorimeter and the annular ring. Through adjustment of the valves at the respective exits, the difference in temperatures at entrance and exit of the calorimeter and the annular ring was the same and equal. When this condition had been reached no heat was being transmitted to or drawn away from the calorimeter and therefore the amount of heat absorbed in the calorimeter was only that transmitted through its exposed face.

MOUNTING At the points where the pipes to the entrance and exit of the annular ring passed through the back of the galvanized iron container, the metal was carefully cut away for a distance of approximately two and onehalf inches in all directions, thus avoiding any error due to heat being conducted from the container to the water pipes. The annular ring was carefully mounted, in the same manner as the calorimeter with its face in the same plane as the calorimeter. Asbestos and Kiesel Guhr was packed solidly in the one-eighth inch clearance between the calorimeter and the ring to keep heat from passing between the two containers.

ADJUSTING IN PLACE The calorimeter was held in place on the face of the sample by means of a frame-work made of iron pipes and pipe fittings. The portions that were to move through appreciable distances were threaded and fitted with nuts to securely lock the frame-work when once it had been adjusted. By means of this frame-work fine adjustments could be made in all directions. The circular band shown in the photograph was the immediate support of the shell of the calorimeter and by its aid a further adjustment to and from the test panel, and also in a rotary direction was obtained. The latter was of great importance in placing the pyrometers in position. The frame-work operated satisfactorily at all times and gave a rigid and solid protection to the pyrometers, which might have been injured had any movement occurred.

## THE WATER SUPPLY

**THE TANK** A tank having a capacity of approximately five gallons was placed on a standard near the ceiling. The supply of water was obtained from the city mains which were connected to the tank. The discharge to the calorimeter and the annular ring was through half inch pipe. An overflow pipe two inches in diameter was provided to keep the water in the tank at a constant level. The supply line was connected with the calorimeter and annular ring by three-eighths inch patrol hose.

**DISCHARGE FITTINGS** The discharge fittings for the calorimeter consisted of half-inch pipe with a one-half inch gate-valve placed in the line to permit adjustment of flow. This was placed on a standard in such a way as to insure a constant head on the system. The exit from the annular ring consisted only of a length of three-eighth inch hose with a valve attached for adjustment of flow.

**ADJUSTMENT OF FLOW** This arrangement gave a constant head on the calorimeter, which was of prime importance. The supply to the tank was adjusted in every test so that the overflow pipe was constantly discharging water. As the position of the discharge fitting from the calorimeter was the same throughout each test, the head was constant and therefore the discharge the same for all periods.

# C H A P T E R I I I

## GENERAL PLAN OF INVESTIGATION

## GENERAL PLAN OF INVESTIGATION

**ESSENTIAL FEATURES** The general plan of investigation of each sample was practically the same, the essential features in each test being the determination of the following:

1. Physical characteristics before exposing to fire;
2. Time and temperature for saturation at all depths for different furnace temperatures;
3. Heat transmitted per unit of area at these saturation points for the different furnace temperatures;
4. Physical characteristics after exposure to fire.

After accurate measurements of each sample had been taken, the form was closely examined for flaws, cracks, scale, broken edges, holes, scabs, lime spots, marks of unequal kiln-heating, hardness, color, etc. Photographs of each sample tested were taken, which are attached, in order to clearly identify these characteristics. The sample was then set in place in the center of the test panel and the calorimeter and pyrometers installed and properly adjusted, and the water and electrical connections made.

**OPERATION** The solid panel of the test wall was then rolled infront of the furnace and the burners set in operation. After the furnace temperature had been properly adjusted, the test panel was rolled in front of the furnace and set flush against its edges. Readings of the pyrometers were taken and subsequently at definite intervals throughout the test. As soon as the temperatures throughout the sample had become constant, for a given furnace temperature, the flow of water through the annular ring and the calorimeter was adjusted to give the same difference in temperatures at entrance and exit. Readings of these temperatures were then taken and recorded. The discharge was then measured for a period of time sufficient in length to avoid errors usually made in an operation of this nature. When the readings of the pyrometers and the thermometers had remained constant for a period varying from thirty minutes to one hour at the given definite temperature in the furnace, the burners were adjusted to give the next temperature desired in the test, and the same procedure followed. Each sample was tested at three different furnace temperatures in this manner, each temperature being maintained until the saturation point at that temperature had been reached. The constancy of the pyrometer and thermometer readings, for a reasonable length of time, indicated that the saturation point had been reached for that particular furnace temperature. In order that the equation of the curve showing the heat transmitted

[illegible]

[illegible] The general pl[illegible]
sample [illegible] [illegible]
essential [illegible]
determination [illegible] the following:

1. Physical char[illegible] [illegible];

2. [illegible] and temperature [illegible] saturation [illegible]
for [illegible];

3. [illegible] area at [illegible]
[illegible];

4. Physical characteristics [illegible].

After [illegible] of each [illegible]
form was closely examined for [illegible], cracks, [illegible]
holes, [illegible], roots, [illegible]
[illegible], color, etc. [illegible]
which [illegible] in order to [illegible]
characteristics. [illegible]
of [illegible] the [illegible]
and properly [illegible]
[illegible].

[illegible]

[illegible] the [illegible]
[illegible] the furrow [illegible]
[illegible], the test [illegible]
[illegible]
[illegible] as the [illegible]
[illegible]

be definite, it was deemed best to test each sample at three different furnace temperatures, these temperatures ranging from approximately 1200 to 2000 degrees Fahrenheit.

After the saturation point at the higheat temperature had been reached and maintained for a reasonable length of time, the gas supply to the furnace was shut off and the furnace and the test panel allowed to cool slowly to normal temperature. The sample was then removed from its setting and its characteristics noted. In addition to the previously mentioned characteristics the following qualities were noted: Depth and degree of calcination and disintegration, depth of vitrification, checking and cracking, defective depth of injury, falling away of faces and edges, and the general change in the texture of the tile. Photographs of each sample after exposure to fire were taken and are shown in Chapter VI.

[illegible] definite, [illegible] caused [illegible]
different [illegible] temperature [illegible]
from approximately [illegible]

[illegible] results [illegible]
the air supply [illegible]
the test panel [illegible]
The sample was [illegible] removed from the [illegible]
characteristics [illegible]. In addition, [illegible]
[illegible]

# C H A P T E R IV

## EXAMINATION, TEST RECORD, AND CALCULATIONS

A. Pyrometer Calibration Data

B. Test No. 1

C. Test No. 2

D. Test No. 3

E. Test No. 4

## PYROMETER CALIBRATION DATA

| Couple No. | 126 | 128 | 130 | 131 | Series 5 |
|---|---|---|---|---|---|
| Melting Point of Tin, | 449 | 449 | 449 | 449 | 449 |
| Voltage (in millivolts) | 2.22 | 2.21 | .79 | .73 | 7.30 |
| Melting Point of Zinc | 786 | 786 | 786 | 786 | 786 |
| Voltage (in millivolts) | 4.60 | 4.59 | 1.59 | 1.50 | 14.86 |
| Melting Point of Copper | 1981 | 1981 | 1981 | 1981 | 1981 |
| Voltage (in millivolts) | 14.32 | 14.29 | 4.9 | 4.65 | |

The above calibration was carried out with the use of Galvanometer #2, which was used in all of the measurements taken in the thesis. Pyrometer, Series 5, was used in connection and in series with a resistance box.

The data for curve #6, for couple Series 5 in connection with Galvanometer #3 and without resistance in circuit, is as foll-ows:-

| Voltage | Temp. |
|---|---|
| 0.00 | 35 |
| 0.82 | 77 |
| 4.00 | 213 |
| 10.30 | 449 |

TEST NO. 1

## FOUR INCH COMMERCIAL FORM OF BUILDING TILE

The sample selected for test was of the ordinary form of commercial building tile with ridged outer surfaces taken at random from a large number of similar forms, but of such quality as to represent an average tile in size, nature of structure, density, color and hardness. Before actual exposure to fire the physical characteristics of the sample were noted in order to afford a comparison with the characteristics shown after expoaure. Photographs were taken in order to more closely accentuate the points of difference. The measurements of the component parts of the sample are shown on Illustration No. V.

# PHYSICAL CHARACTERISTICS BEFORE EXPOSURE

**EXPOSED SURFACE** The flange which was designated as that which would be exposed to the fire was smooth in appearance and was a deep tan in color over the entire surface. The ridges were uniform and equal in depth, with the exception of that part of the flange which was directly over the webs where they were still uniform in depth but not of the same width as the majority. The surface was uniform in texture and density with no evidence of foreign ingredients. The flange was hard and solid throughout, devoid of all cracks, and gave forth a sharp metallic sound when struck.

**UNEXPOSED SURFACE** The unexposed surface of the sample was fairly smooth with uniform and equal depths in the ridges. In two places the ridges were slightly broken and on one corner a small chip had been broken off. A few small air holes were present but none had any appreciable depth. The entire interior of the form was very smooth, had no air holes, and was uniform in texture.

**THE ENDS AND WEBS** The ends of the sample were rather rough, and the webs were slightly misshaped, probably due to unskillful handling of the molded form preliminary to kiln-drying. The ends, sides and flanges were at right angles in all places and the whole presented a rectangular, symmetrical form.

**SETTING** After the physical characteristics had been noted, the sample was placed in one end of the test wall with both faces flush with the framework surrounding it. The calorimeter was then placed flush with the back of the sample, and the pyrometers located in their respective places. Two holes had previously been drilled in the back of the sample according to a template of the holes in the calorimeter, which facilitated the insertion of the pyrometers in their correct positions. Three pyrometers were inserted in the sample. One of these was placed on the inside surface of the unexposed.face. The second was placed even with the inside surface of the unexposed face, while the third was placed on the outside surface of the unexposed face. This arrangement was chosen in order to give, if any, information regarding the value of the air space present in this particular form.

[illegible]

[illegible] The fitting which was [illegible] could be scraped off [illegible] appearance and was [illegible] entire surface. The [illegible] with the exception of that part of the fitting [illegible] over the area where the [illegible] the same color as the majority. The surface [illegible] texture and density [illegible] no evidence of [illegible] The [illegible] gave forth a very metallic sound when struck.

[illegible] The [illegible] figure. [illegible] ly uneven and [illegible] corners small [illegible] The small air holes were [illegible] [illegible]

[illegible] The end of the crystal [illegible] [illegible] right angles [illegible] all surfaces [illegible] symmetrical form.

[illegible] The only [illegible] with corresponding [illegible] The outlines [illegible] of the [illegible] sample, [illegible] or water, which [illegible] their correct position [illegible] the sample. [illegible] the surfaces. The [illegible] each of [illegible] certain analysis of the exposed [illegible] [illegible] if any, failed [illegible] of the air space result in this [illegible]

## THE TEST

OPERATION — As soon as the apparatus had been mounted on the tile form, the blank portion of the test wall was rolled into place in front of the furnace, and the furnace set in operation. When the temperature in the furnace had reached approximately 1200°F. The test wall was rolled until the end containing the sample to be tested was directly exposed to the fire. Readings of the furnace temperature were obtained by means of a furnace couple, placed in contact with the center of the exposed face of the sample. Readings of the pyrometers were taken at ten minute intervals. As the temperatures became constant throughout the sample, the flow of water through the calorimeter and the annular ring was adjusted to give the same difference in temperature between their respective entrances and exits. During the time when the readings of the pyrometers and the thermometers showed but slight variation, observations were frequently made in order to more closely judge the correctness of the temperatures taken as saturation points. When the readings of the pyrometers had become constant, final readings of the temperatures of the water, at entrance and exit, of the annular ring and the calorimeter, were taken and the rate of flow determined for a period of time sufficient in length as to insure a fair average value of the discharge.

TEMPERATURE RISE — As rapidly as possible, the temperature in the furnace was then raised to 1600°F by adjusting the gas and air supply to the burners. Readings similar to those enumerated in the first part of the test were taken, and at the point of saturation the rate of flow, and the temperatures of the water passing through the annular ring and the calorimeter were noted. The burners were again adjusted so as to give a furnace temperature of 1800°F and readings taken at ten minute intervals until the saturation points at all depths were reached, when the rate of flow and the temperatures of the water passing through the calorimeter and the annular ring were noted.

SHUTTING DOWN — After the last reading had been taken, the gas and air supply were shut off and the furnace allowed to cool slowly. When the test wall and furnace were thoroughly cooled the apparatus was taken down and the sample form of tile carefully removed. Careful observations of the physical characteristics of the sample were then made, and the points of difference, before and after exposure to fire, noted.

## PHYSICAL CHARACTERISTICS AFTER EXPOSURE

EXPOSED SURFACE

The color of the sample was practically the same, or at the most, only a slightly lighter shade. When tapped, it gave forth a hollow sound. The ridges, on the surface of the sample were unchanged. There was a slight crack three and one-half inches long over one web and another extending the entire length of the tile over the other web. There was a slight crack from the second web to the edge about two inches from the center of the tile.

UNEXPOSED SURFACE

The unexposed surface was unchanged in color, texture and physical characteristics. This was due in all probability to the cooling effect of the calorimeter and the annular ring.

ENDS AND WEBS

There was a crack all along one side which was irregular in direction and size. This crack was at the joining point of the exposed surface and the end. There was a slight crack across the middle of this end from the exposed face to the unexposed face. The other end had a heavy crack along its whole length, at the joining point of the exposed surface and the end. All the webs were cracked along the exposed face.

# TEST #1
## Miscellaneous Data

Pyrometers:- #1 = calibration curve #2 for pyrometer #128
#2 = calibration curve #3 for pyrometer #130
#3 = calibration curve #5 for pyrometer #Series 5.

### 1st Saturation Point

Difference in temperature between entrance and exit of calorimeter = 2.12°F

Weight of water discharged
= 57.48# in 12 minutes
= 4.79# /min.

### 2nd Saturation Point

Difference in temperature between entrance and exit of calorimeter = 3:15°F

Weight of water discharged
= 67.35# in 15 minutes
= 4.49#/min.

### 3rd Saturation Point

Difference in temperature between entrance and exit of calorimeter = 4.86°F

Weight of water discharged
= 54.625# in 15 minutes
= 3.64#/min.

## TEST #1
## Calculations

### 1st Saturation Point

Furnace temperature = 1235
Temperature at back of tile = 190
Difference in temperature = 1045

Difference in temperature between entrance and exit of calorimeter = 2.12°F
Rate of flow through calorimeter = 4.79#/min.

Heat transmitted = 1.834 x 4.79 x 2.12
= 18.613 Btu/sq.ft./min.

Thermal conductivity, K = $\frac{18.613 \times 3.76}{1045}$

= .0669

### 2nd Saturation Point

Furnace temperature = 1600
Temperature at back of tile = 321
Difference in temperature = 1279

Difference in temperature between entrance and exit of calorimeter = 3.15°F
Rate of flow thru calorimeter = 4.49#/min.

Heat transmitted = 1.834 x 4.49 x 3.15
= 25.938 Btu/sq.ft./min.

Thermal conductivity, K, = $\frac{25.838 \times 3.76}{1279}$
= .07625

### 3rd Saturation Point

Furnace temperature = 1835
Temperature at back of tile = 341
Difference in temperature = 1494

Difference in temperature between entrance and exit of calorimeter = 4.86°F
= 3.64#/min.

Heat transmitted = 1.834 x 3.64 x 4.86
= 33.443 Btu/sq.ft./min.

Thermal Conductivity, K, = $\frac{33.44 \times 3.76}{1494}$

= .0845

NOTE:-

The factor 1.834 used in the calculations of these tests is obtained as follows:-

The area of the calorimeter in square feet

$$= \frac{\pi \left(\frac{10}{12}\right)^2}{4}$$

$$= \frac{100\pi}{576}$$

$$\equiv .545 \text{ sq. ft.}$$

As the heat transmitted through the samples is to be expressed in Btu/sq.ft. the factor to be used is

$$\frac{1.000}{.545} = 1.834$$

T E S T NO. 2

SAMPLE OF SOLID TILE.

This test was made on a sample of solid tile, ground to an even thickness as shown in the data. The grade and quality of the tile was the same as used in the three other tests.

## PHYSICAL CHARACTERISTICS BEFORE EXPOSURE AND SETTING

**SIZE OF SAMPLE** The sample chosen for this test had an average thickness of 1.088 inches, the limits from which this average was taken being 1.07 inches to 1.12 inches. The width of the face was 11 inches while the length was 17 inches.

**THE SURFACES** Both surfaces were very smooth and showed no cracks nor flaws of appreciable extent. They were permeated with small air holes but the texture of the tile as a whole was fine grained and smooth. The surfaces were a deep tan in color and even throughout. By a comparison of the texture, hardness and looks of this sample with that of the other samples tested, it would seem probable that the composition of all the forms was the same.

**THE SETTING** The setting for this sample was somewhat different from that employed for the other samples inasmuch as the thickness of this sample was such that it would not facilitate the building of a wall equal in thickness to the sample. The sample was placed in a wall of ordinary brick four inches thick with the unexposed surface flush with the back of the wall.

The calorimeter was then placed against the unexposed surface of the sample and a pyrometer inserted so as to be in direct contact with the tile. The water and electrical connections were then made and the ordinary procedure followed. Readings of the temperatures were taken at five minute intervals because the thickness of the sample was such that the heat was transmitted at a much faster rate than in other tests.

## PHYSICAL CHARACTERISTICS AFTER EXPOSURE

CHANGES The character of this sample was affected in only a few ways by exposure to fire. There was only a slight change in color, the change being a slight decrease in the reddish tint. The soundness was affected only a trifle,as the sample when struck gave forth a fair metallic ring. No vitrification or calcination could be noticed. No cracks nor flaws other than those present before exposure were to be seen.

## TEST #2
## Miscellaneous Data

Pyrometers:- #1 = Calibration curve #2 for pyrometer #128

### 1st Saturation Point

Difference in temperature between entrance and exit of
calorimeter = 4.05°F

Weight of water discharged
= 58.71# in 14 minutes
= 4.19#/min.

### 2nd Saturation Point

Difference in temperature between entrance and exit of
calorimeter = 6.03°F

Weight of water discharged
= 61.656# in 14 minutes
= 4.40#/min.

### 3rd Saturation Point

Difference in temperature between entrance and exit of
calorimeter = 8.10°F

Weight of water discharged
= 61.609# in 14 minutes
= 4.40#/min.

# TEST #2
## Calculations

### 1st Saturation Point

Furnace temperature = 1201
Temperature at back of tile = 264
Difference in temperature = 937

Difference in temperature between entrance and exit of calorimeter = 4.05°F
Rate of flow thru calorimeter = 4.194#/min.

Heat transmitted = 1.834 x 4.194 x 4.05

= 31.03 Btu/sq.ft./min.

Thermal Conductivity, K, = $\frac{31.03 \times 1.088}{937}$

= .0357

### 2nd Saturation Point

Furnace temperature = 1581
Temperature at back of tile = 340
Difference in temperature = 1241

Difference in temperature between entrance and exit of calorimeter = 6.03°F
Rate of flow thru calorimeter = 4.403#/min.

Heat transmitted = 1.834 x 4.403 x 6.03

= 48.55 Btu/sq.ft./min.

Thermal conductivity, K, = $\frac{48.55 \times 1.088}{1241}$

= .0422

### 3rd Saturation Point

Furnace temperature = 1922
Temperature at back of tile = 391
Difference in temperature = 1531

Difference in temperature between entrance and exit of calorimeter = 8.10°F
Rate of flow thru calorimeter = 4.40#/min.

Heat transmitted = 1.834 x 8.10 x 4.40
= 65.22 Btu/sq.ft./min.

Thermal conductivity, K, = $\frac{65.22 \times 1.088}{1531}$
= .0460

# T E S T NO. 3

## SPECIAL FORM OF TILE MADE TO SPECIFICATIONS.

This test was made on a special form of tile as shown in Illustration # VI. The grade and quality of the tile used was the same as that used in the three other tests.

## PHYSICAL CHARACTERISTICS BEFORE EXPOSURE AND SETTING

THE FORM — The form used in this test was made of four slabs of tile with dimensions shown in Illustration No.VI. The slabs were smooth in appearance and of the same color, texture and hardness. Each slab was separated by ribs at either end made of long strips of tile embedded in cement mortar. When completed the form looked like an ordinary piece of building tile with three air spaces.

EXPOSED SURFACE — The surface that was exposed to the fire was comparatively smooth in appearance with a deep reddish brown color. The entire surface was somewhat indented with black spots varying in size from one-sixteenth to three-sixteenths inches. A few small chips had been broken from the surface, but the damage was very slight. On one edge of the sample a very slight crack was noticeable, but the remainder of the flange was unmarred. When struck it gave forth a sharp metallic ring.

UNEXPOSED SURFACE — The back flange of the sample was very smooth but, like the exposed flange, was somewhat indented with small black spots. The color of this flange was a little more yellow than the exposed surface. The other two flanges possessed the same characteristics as did the back flange. Thetexture of the slabs was the same as shown where the edges were broken or scarred. The material used in their manufacture was fine except for small pebbles, distributed throughout, which were less than one-eighth inch in diameter.

THE SETTING — The setting, on account of the thickness of this sample, was a little different than that used in the other tests. It was found necessary to place four and one-half inch bricks on all sides. Layers of these bricks were used for a considerable distance from the sample, and then ordinary brick was used for filling the remainder of the panel. To prevent any possibility of the exposed surface falling away from the sample, it was deemed necessary to use some means of binding the flanges together. The means adopted consisted of placing two right angle irons, one on each side of the exposed face and embedding them in the brick-work for a distance of three inches. Pyrometers were placed on the face of each slab nearest the calorimeter. The water and electrical connections were then made and the test conducted as given in Test No.1.

# PHYSICAL CHARACTERISTICS AFTER EXPOSURE

CHANGES The texture of the exposed surface was not appreciably changed but there was a decided change in color, having changed to a deep brown. A few small additional chips had been broken off but otherwise the surface was the same as before exposure. Calcination and vitrification were noticed only in the first flange, the remaining flanges of the form not being affected by fire.

# TEST #3
## Miscellaneous Data

Pyrometers:- #1 = calibration curve #4 for pyrometer #131
#2 = calibration curve #2 for pyrometer #128
#3 = calibration curve #3 for pyrometer #130
#4 = calibration curve #5 for pyrometer #Series 5

### 1st Saturation Point

Difference in temperature between entrance and exit of calorimeter = 2.95$^\circ$F

Weight of water discharged
= 70.71# in 16.25 minutes
= 4.35#/min.

### 2nd Saturation Point

Difference in temperature between entrance and exit of calorimeter = 4.65$^\circ$F

Weight of water discharged
= 59.23# in 16 minutes
= 3.70#/min.

### 3rd Saturation Point

Difference in temperature between entrance and exit of calorimeter = 6.11$^\circ$F

Weight of water discharged
= 55.92# in 15 minutes
= 3.72#/min.

# TEST #3
## Calculations

### 1st Saturation Point

Furnace temperature = 1210
Temperature at back of tile = 97
Difference in temperature = 1113

Difference in temperature between entrance and exit of calorimeter = 2.95°F
Rate of flow thru calorimeter = 4.35#/min.

Heat transmitted = 1.834 x 4.35 x 2.95
= 23.5 Btu/sq.ft./min.

Thermal conductivity, K, $= \frac{21.6 \times 4.59}{1113}$
== .097

### 2nd Saturation Point

Furnace temperature = 1500
Temperature at back of tile = 133
Difference in temperature = 1367

Difference in temperature between entrance and exit of calorimeter = 4.65°F
Rate of flow thru calorimeter = 3.70#/min.

Heat transmitted = 1.834 x 3.70 x 4.65
= 31.5 Btu/sq.ft./min.

Thermal conductivity, K, $= \frac{28.8 \times 4.59}{1367}$
= .105

### 3rd Saturation Point

Furnace Temperature = 1831
Temperature at back of tile = 144
Difference in temperature = 1687

Difference in temperature between entrance and exit of calorimeter = 6.11°F
Rate of flow thru calorimeter = 3.72#/min.

Heat transmitted = 1.834 x 3.72 x 6.11
= 4.16 Btu/sq.ft./min.

Thermal conductivity, K, $= \frac{49.5 \times 4.59}{1687}$
= .114

# T E S T NO. 4

## SPECIAL FORM OF TILE MADE TO SPECIFICATIONS

This test was made on a special form of tile similar in make-up to that used in the third test.

# PHYSICAL CHARACTERISTICS BEFORE EXPOSURE AND SETTINGS

**THE FORM** The form used in this test was made of four slabs of tile with dimensions as shown on Illustration No. VI. The slabs were smooth in appearance and of the same color, texture and hardness. Each slab was separated by ribs at either end, made of long strips of tile embedded in cement mortar. When completed the form looked like an ordinary piece of building tile with three air spaces.

**EXPOSED SURFACE** The exposed surface of the form was smooth in appearance. No large air holes were present but the flange was porous throughout. The predominating color was reddish brown but in one corner the color was a light yellow. In a few places small chips had been broken off but the damage was not sufficient to cause any discrepancies in the results.

**UNEXPOSED SURFACE** The unexposed surface of the sample was a light yellow in color over about one-half of its area and an orange color over the other half. The flange was smooth and solid throughout. The ends, sides, and faces of the sample were square.

**THE SETTING** The sample was placed in a wall of ordinary brick laid edgeways, the unexposed surface of the sample being laid flush with the outer edge of the wall. The calorimeter was placed in contact with the surface of the sample. The pyrometers were then inserted and the water and electrical connections made. The procedure as outlined in Test No. 1 was then followed. Readings of Pyrometers and temperatures were taken every fifteen minutes.

# TEST #4
## Miscellaneous Data

Pyrometers:- #1 = calibration curve #4 for pyrometer #131
#2 = calibration curve #2 for pyrometer #128
#3 = calibration curve #3 for pyrometer #130
#4 = calibration curve #6 for pyrometer #Series 5

### 1st Saturation Point

Difference in temperature between entrance and exit of calorimeter = 1.26°F

Weight of water discharged
= 55.02# in 20 minutes
= 2.75#/min.

### 2nd Saturation Point

Difference in temperature between entrance and exit of calorimeter = 2.01°F

Weight of water discharged
= 61.06# in 25 minutes
= 2.44#/min.

### 3rd Saturation Point

Difference in temperature between entrance and exit of calorimeter = 2.43°F

Weight of water discharged
= 43.73# in 13 minutes
= 3.36#/min.

TEST NO. 4
Calculations

1st Saturation Point

| | | |
|---|---|---|
| Furnace temperature | = | 1230 |
| Temperature at back of tile | = | 80 |
| Difference in temperature | = | 1150 |

Difference in temperature between entrance and exit of calorimeter $= 1.26^{\circ}F$

Rate of flow thru calorimeter = 2.75#/min.

Heat transmitted = 1.834 x 2.75 x 1.26
= 6.33 Btu/sq.ft./min.

Thermal conductivity, K, $= \frac{6.33 \times 7.545}{1150}$
= .0415

2nd Saturation Point

| | | |
|---|---|---|
| Furnace temperature | = | 1537 |
| Temperature at back of tile | = | 95 |
| Difference in temperature | = | 1442 |

Difference in temperature between entrance and exit of calorimeter $= 2.01^{\circ}F$

Rate of flow thru calorimeter = 2.44#/min.

Heat transmitted = 1.834 x 2.44 x 2.01
= 8.96 Btu/sq.ft./min.

Thermal conductivity, K, $= \frac{8.96 \times 7.545}{1442}$
= .0468

3rd Saturation Point

| | | |
|---|---|---|
| Furnace temperature | = | 1872 |
| Temperature at back of tile | = | 134 |
| Difference in temperature | = | 1738 |

Difference in temperature between entrance and exit of calorimeter $= 2.43^{\circ}F$

Rate of flow thru calorimeter = 3.36#/min.

Heat transmitted = 1.834 x 3.36 x 2.43
= 11.28

Thermal Conductivity, K, $= \frac{14.93 \times 7.545}{1738}$
= .049

# C H A P T E R V.

## CONCLUSIONS

## PRELIMINARY DISCUSSION

DEFINITION Suppose we have a slab of tile of unit thickness with one face at a temperature of $T^o$ and the other face at a temperature of $(T-1)^o$. The quantity of heat which passes per unit of time through each unit of area of the tile is called the Thermal Conductivity of the tile. In its most simple form the law can be expressed best as follows:

$$H = \frac{ktA(T_2-T_1)}{L}$$

where

H = quantity of heat transmitted

K = proportionality factor, depending upon the substance, and is called the coefficient of thermal conductivity.

t = increment of time during which the process continues.

A = area of cross-section through which the heat passes.

$T_2-T_1$ = temperature difference between the two surfaces.

L = thickness of the material.

APPLICATION In the tests herein described it has been the aim of the writer to devise a method whereby they could measure H, the quantity of heat transmitted. As an accurate and precise measurement of this heat was anticipated as impossible, the apparatus was developed with the idea of eliminating most of the gross efficiency losses, and obtaining results which could be used in a relative study of the various forms. Each test was made under the same conditions, and therefore, the heat measured was at least proportional to the total heat in each test and the results obtained can be said to be relative. In either case, whether the losses are a constant quantity or whether percentages of the whole, the relativity of the results would be unchanged.

IMPROVEMENTS As stated previously, the results obtained in this thesis are not absolutely accurate, and at this point, a word might be said as to new ideas which may be incorporated in a new and better design of calorimeter. It is suggested that the calorimeter be made smaller, preverably elliptical in shape, with major and minor axes of ten inches and seven inches respectively. The annular ring, if made with its major and minor axes equal to thirteen inches and ten inches respectively, will provide a means of insulation for the sides of the calorimeter that will be as perfect, under the operating conditions, as is possible. The remaining features of construction can be made the same as those in the calorimeter used in this thesis, and it is felt that a calorimeter constructed on these lines will furnish the most accurate means for the measurement of heat transmitted through various materials.

## GENERAL CONCLUSIONS

TIME-TEMPERATURE The time-temperature curves for all of the samples tested show but a few individual characteristics that can be called worthy of mention. It is to be noticed that Curve C of Curve #7 and Curve C of Curve #13 have a slope quite different at one point than any of the other curves. This point is at the temperature of 212° Fahrenheit. From these curves it can be seen that the temperature remains constant for a considerable period of time at this point, which, in all probability, is due to the presence of an appreciable amount of moisture, which, until driven off, would keep the temperature constant at this point. The absence of this characteristic on the other curves can probably be traced to the rapid rise in temperature at this point, this rise being of such degree as to drive the moisture from the sample at a very short interval of time.

The curve of the furnace temperatures for each test shows, in general but little variation. Some question might arise as to the saturation points obtained in some cases, but it can be stated here that the furnace temperatures, in some instances, varied considerably and thereby caused a change in temperature throughout the sample. These changes, particularly at points of saturation, were carefully noted, and, during the period when it seemed that the temperatures were becoming constant, readings were continually taken between intervals in order to insure absolutely accuracy in regard to the temperatures taken as saturation temperatures. In general, however, the slope of all the curves at saturation temperatures is horizontal.

TEST #1 Curves A and C of Curve #7 give some idea of the value of confined air spaces in building tile, the temperature difference through an air space of 2.48 inches being from 250° to 300°. Another peculiar characteristic to be noted is the unequal differences in temperature between, first, Curve A and curve of furnace temperatures, and, second, Curve B and Curve Z. This difference of the differences varies from 100° to 200°, and to what this difference can be traced is a question that cannot, at present, be answered.

TEST #3
TEST #4 A fact to be noted in regard to the curves shown for special samples #1 and #2 is the higher temperatures throughout, for the same furnace temperatures. This is due to the smaller air spaces and the thinner flanges, but no definite conclusion at this point can be drawn as to the relative value of either of these factors. The fact remains however that the larger the air spaces and the thicker the flanges the less will be the temperatures throughout, and, also, the transmission of heat, per unit of area, will be less.

Another factor to be noted is the relation between the temperature shown in Curves A and C on Curve #7 and those shown in Curves A and D on Curves #13 and #16. It will be seen that Curve A of Curve #7 is lower than the corresponding curves on Curve #13 and #16, and also, that Curve C is higher than those shown on Curves #13 and #16. This might be reasonably explained by the presence of the webs in the sample used in Test #1, for, as conducting agents which were better than the air between the inner and outer flanges, these webs would transmit heat from one flange to another with such rapidity as to cause appreciable decrease of temperature at one face and an appreciable increase at the other.

Btu. CURVES The Btu.-Difference in temperature curves for the four tests show very clearly the limits of accuracy of the calorimeter. The shape of all the curves is practically a straight line, but the limits of accuracy are about 400° Fahrenheit in all cases, that is, for a difference in temperature of about 400° or less, the calorimeter used in these tests is not sensitive enough to measure the heat transmitted. It will be seen therefore that the amount of heat transmitted can only be compared relatively with that transmitted through the other sample, but, since the degree of accuracy is approximately the same in all cases, the comparison of these relative values is correct.

K - CURVES The K -Difference in temperature curves show, in all cases but one, a slope that is peculiar. Whether this is due to the presence of the air spaces or to various other factors, cannot at this stage of the research be stated. By observing Curve #9 it will be seen that the curve passes through absolute Zero. This is the ideal curve, but in the other three tests it will be noticed that the curve has a much different slope. Curve #12, showing K plotted against difference in temperature, comes the closest to conforming to the ideal curve, and it is probable that with more refined methods this curve would become the ideal curve for thermal conductivity. The thermal conductivity of any material increases directly in proportion to the temperature, and thus forms a straight line passing through absolute zero. Whether this is a condition that is obtainable when different conducting agents are placed in series with each other, as the air and tile in the special forms, is a question that is at present not capable of being answered. The thermal conductivity of air and tile are different, and whether the combination of them under the conditions present in these tests would produce an ideal curve is a question which can be answered only by further tests on samples similar to those used in this thesis.

VALUE AS FIREPROOFING

As to value as fireproofing materials, a generality may be stated which will cover all the samples tested. By assuming a sample of solid tile equal in thickness to each of the samples, and calculating, from the general heat equation, the quantity of heat transmitted through each of these solid samples, it will be seen that, in every case, the heat transmitted through the solid sample is less than that transmitted through the sample to which it is equal in thickness. The difference between the amounts of heat transmitted through the samples of solid tile and the other samples varies, but this amount is least in case of special form #2 used in Test #4. By comparing this test with that of special form #1, it can be seen that the larger the air spaces, the greater the resistance to the transmission of heat, and therefore the more valuable is that form as a fireproofing material. This is further substantiated by referring to results of Test #1, although, in this case, the results cannot be absolutely compared, because of the presence of webs of tile in this form.

It would seem, therefore, that, disregarding for the moment the factors of expense and the difficulties encountered when used as a material for building construction, tile of the solid form is the best for use as a fireproofing material. The introduction of air spaces in the design of any form will materially decrease the value of that form as a fireproofing material, but, if air spaces are to be introduced in the design, it would seem advisable that these air spaces be made as large as practicable.

# C H A P T E R VI

## ILLUSTRATIONS, CURVES AND SKETCHES

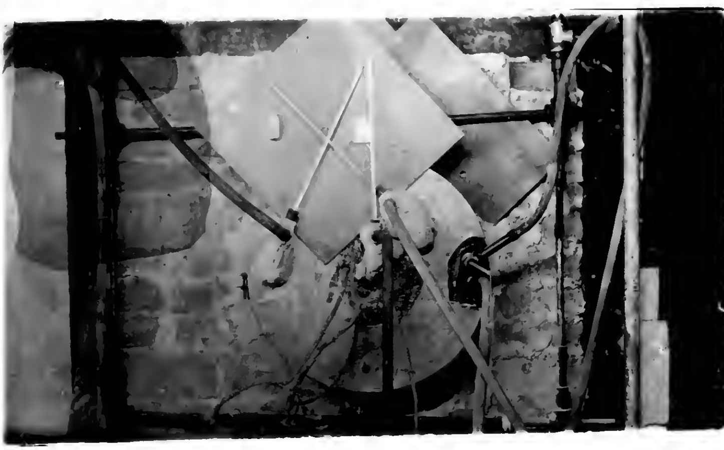
# SKETCHES

PHOTOGRAPHS

No. 1

No. 2

No. 3

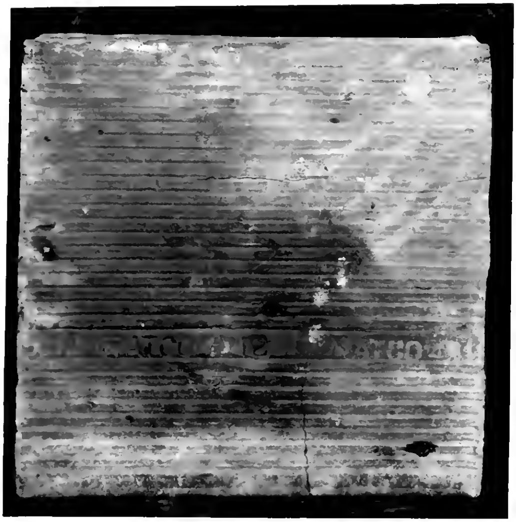


No. 4

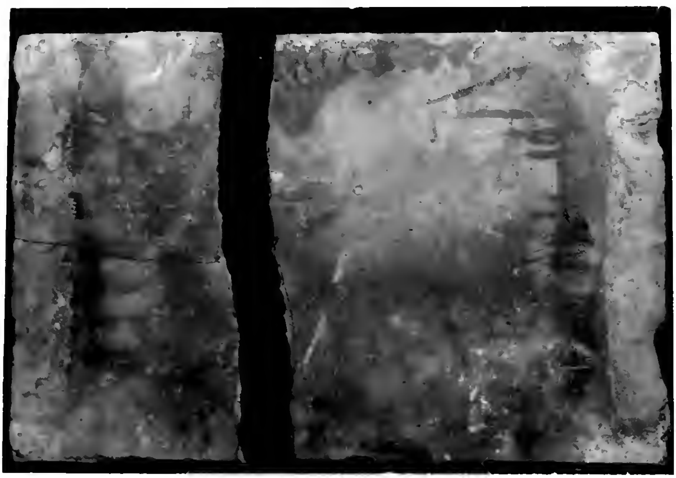
No. 5

No. 6

5



*No. 7*

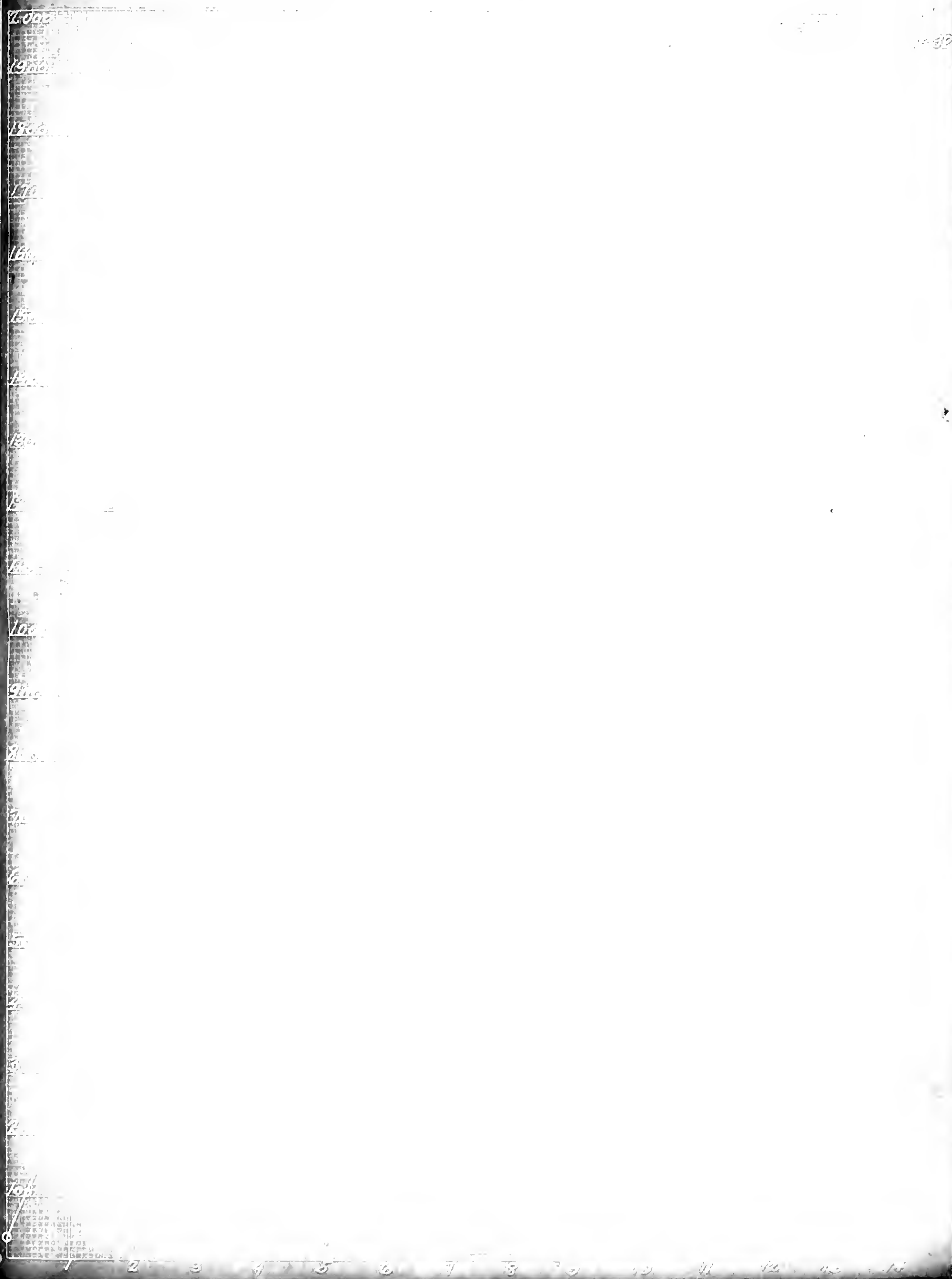


*No. 8.*

No. 9

No. 10

CURV ES




2000
1900
1800

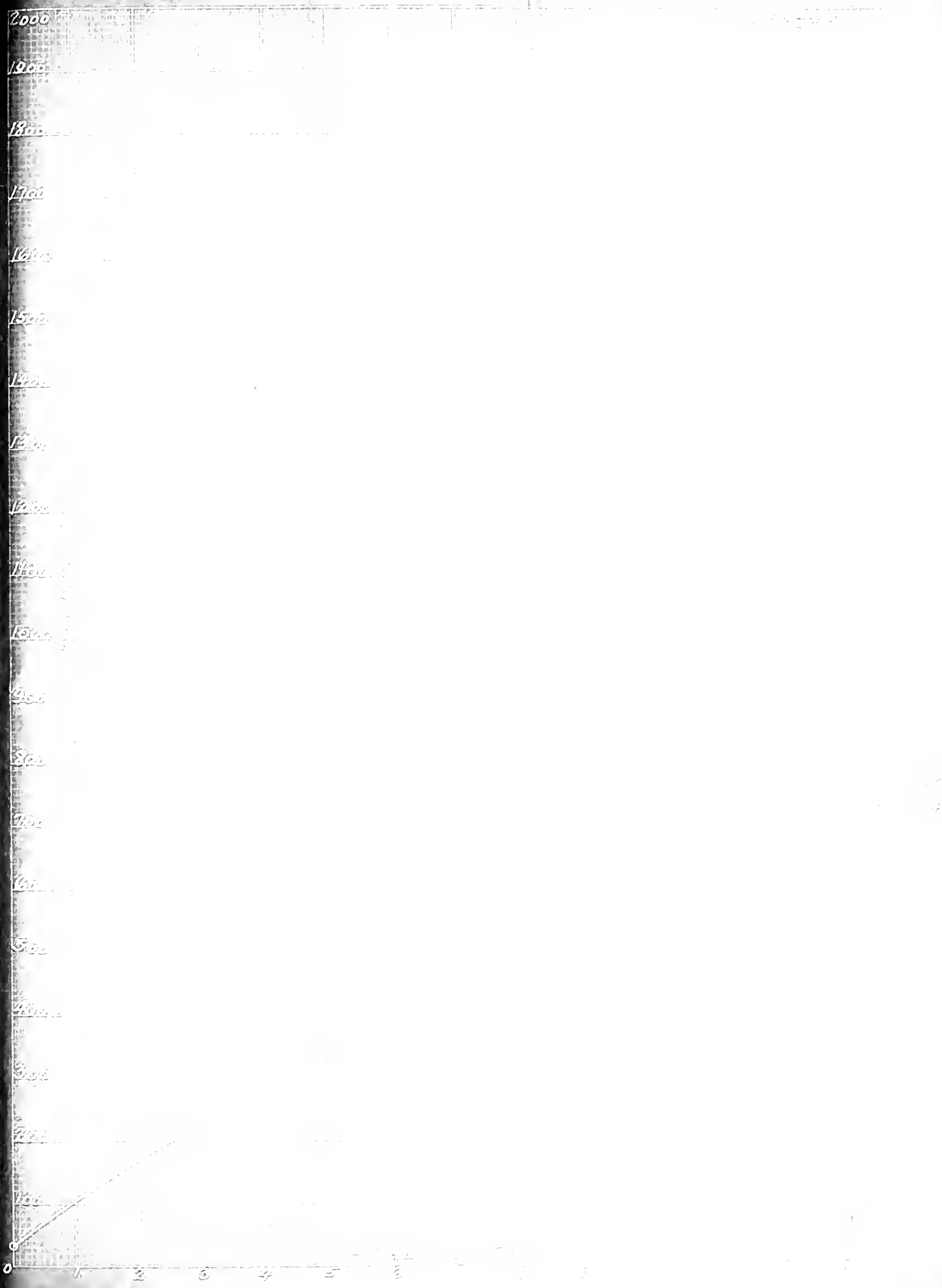
2000

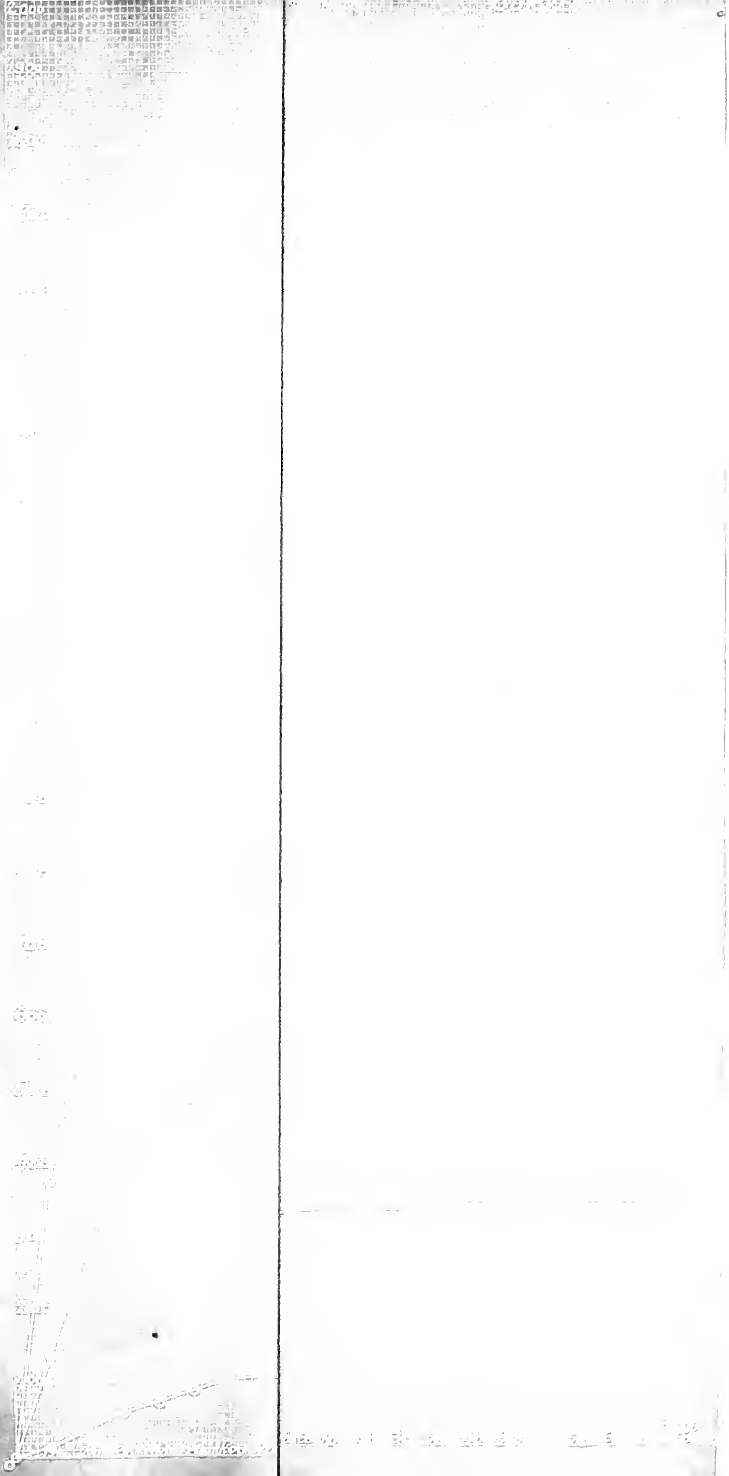
1900

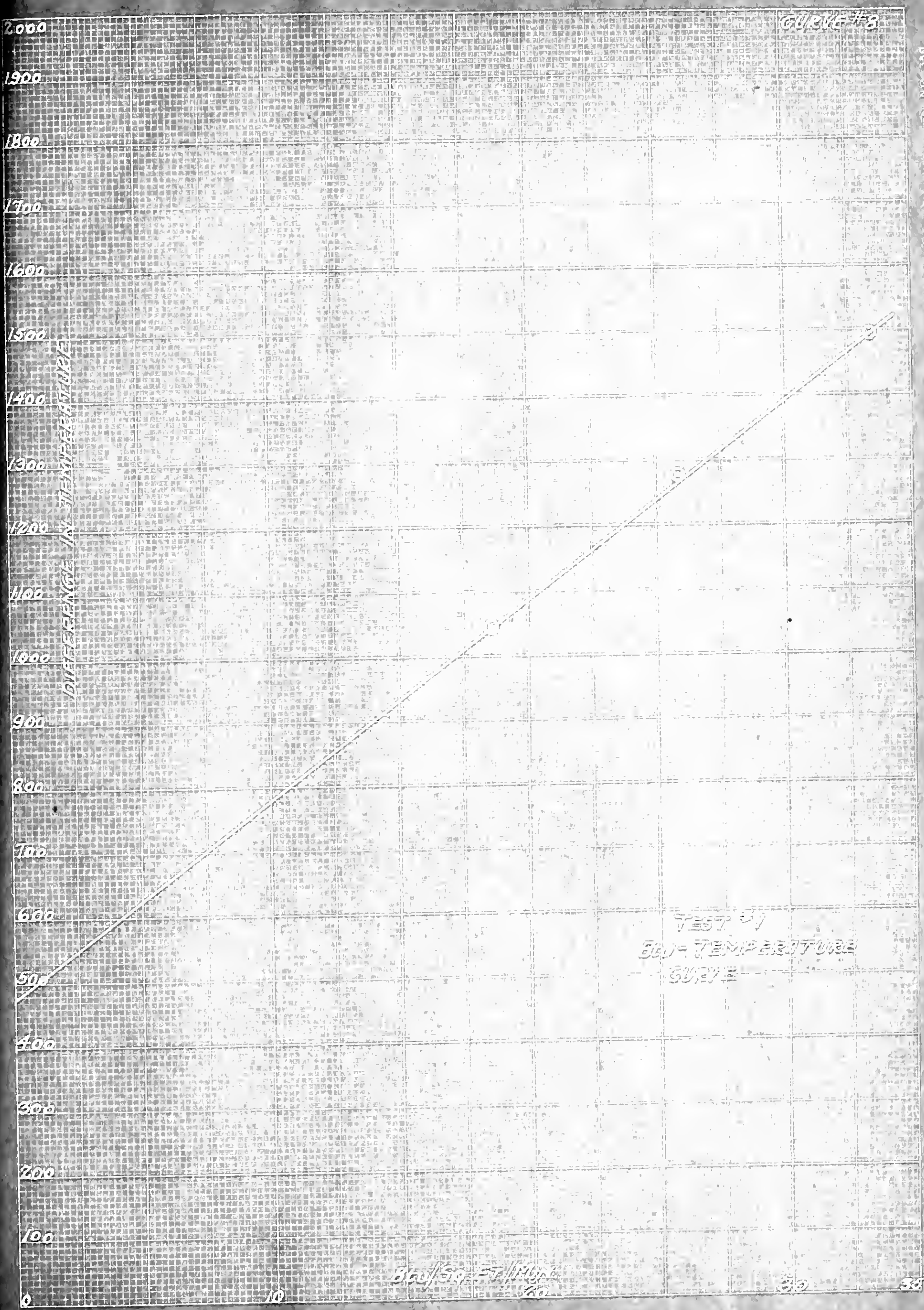
1800

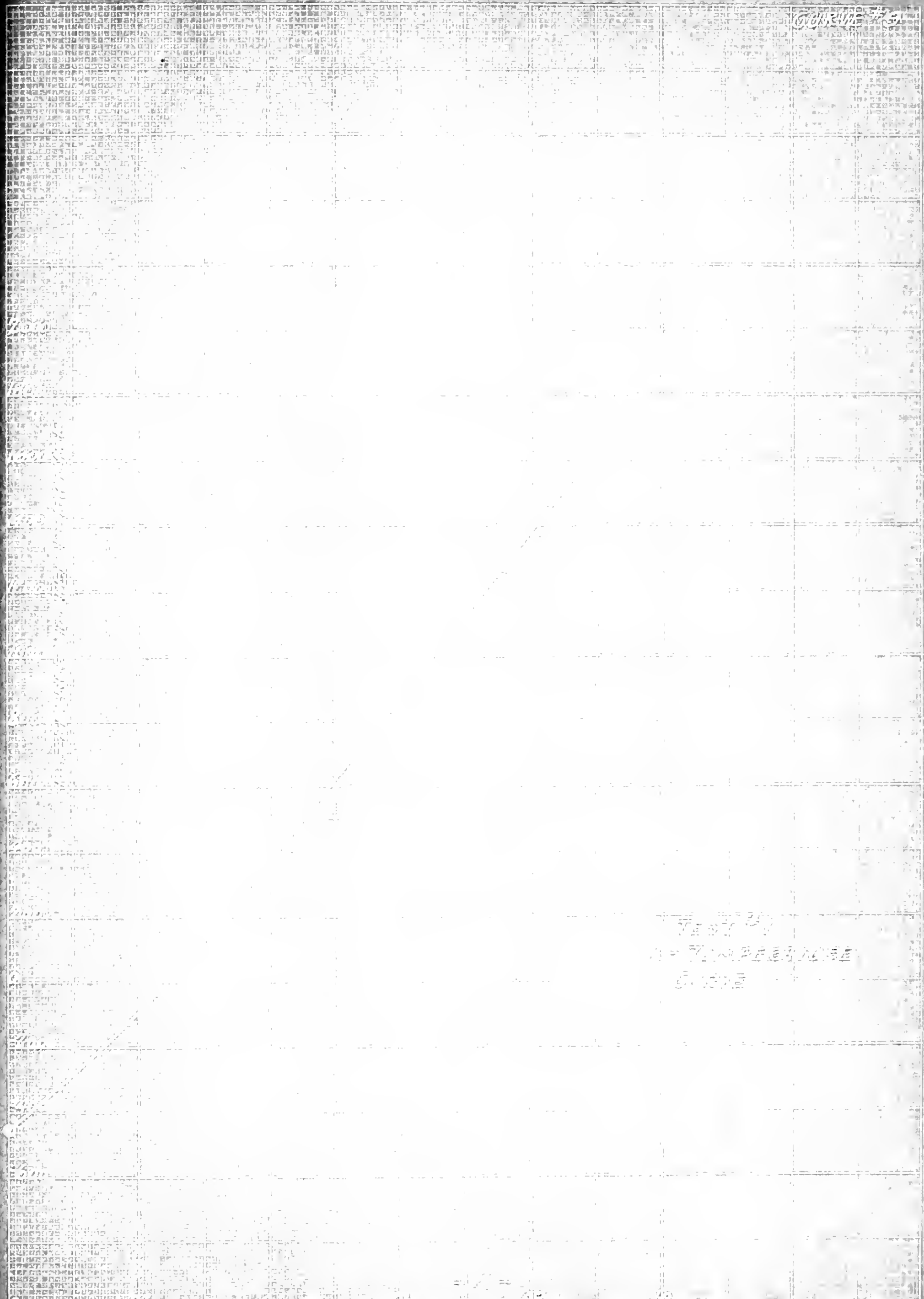
0

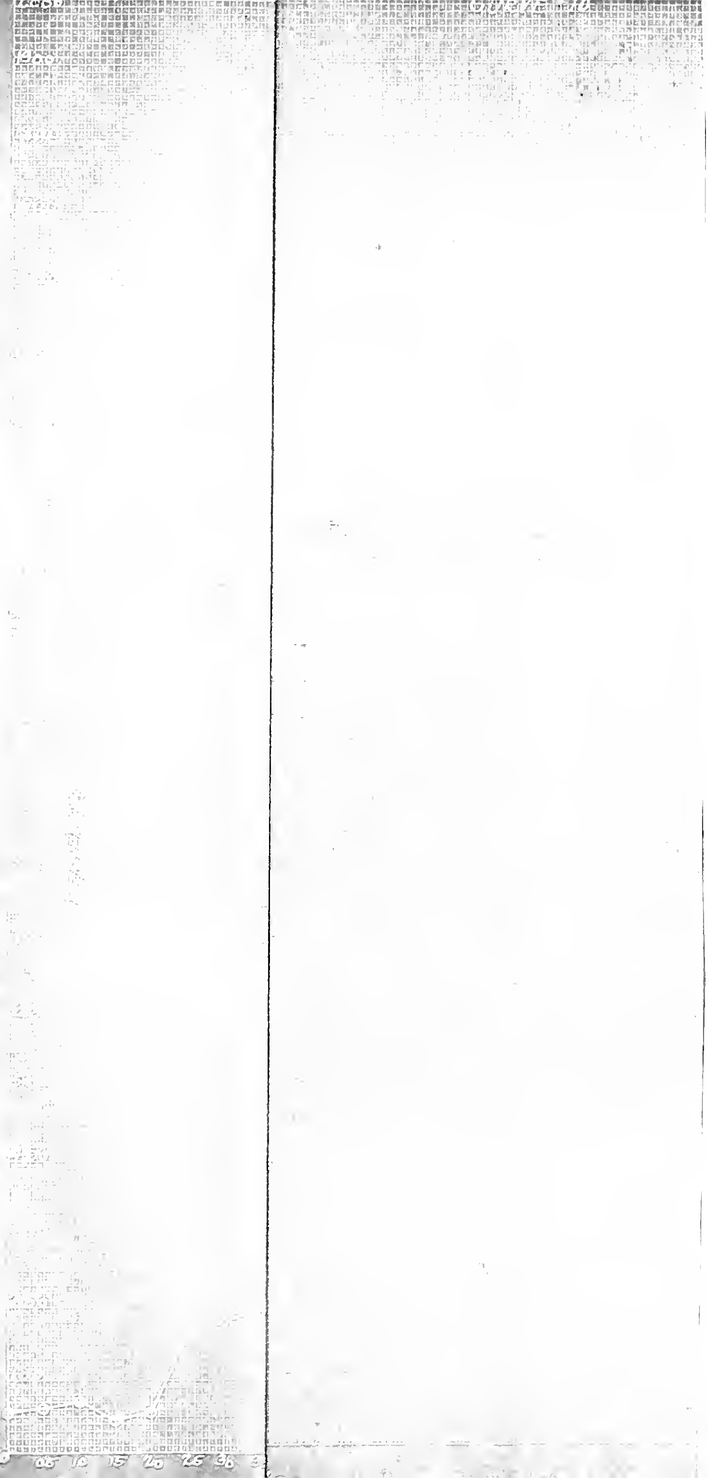

2000
1900
0

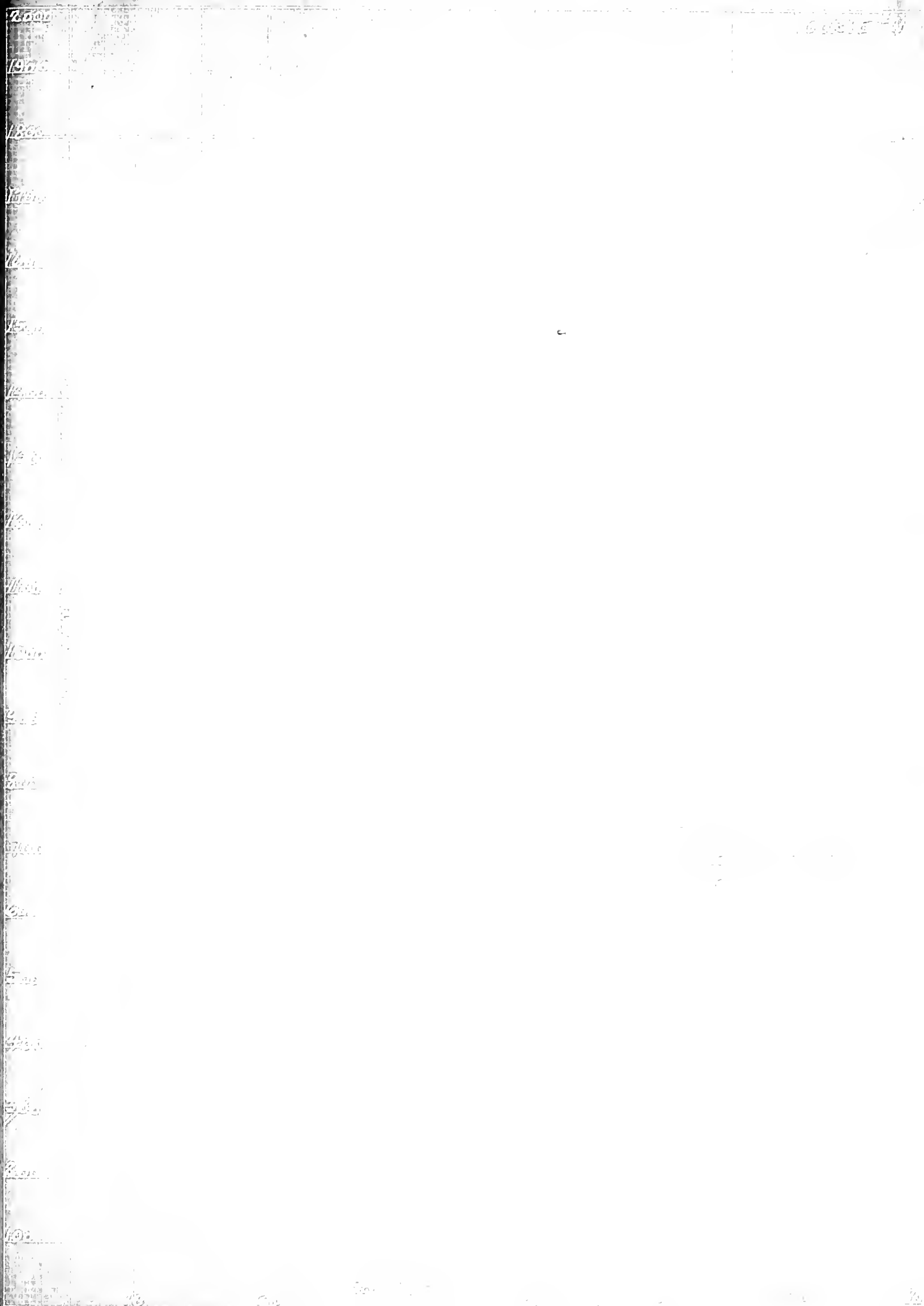

2000
1900
1800
1700
0

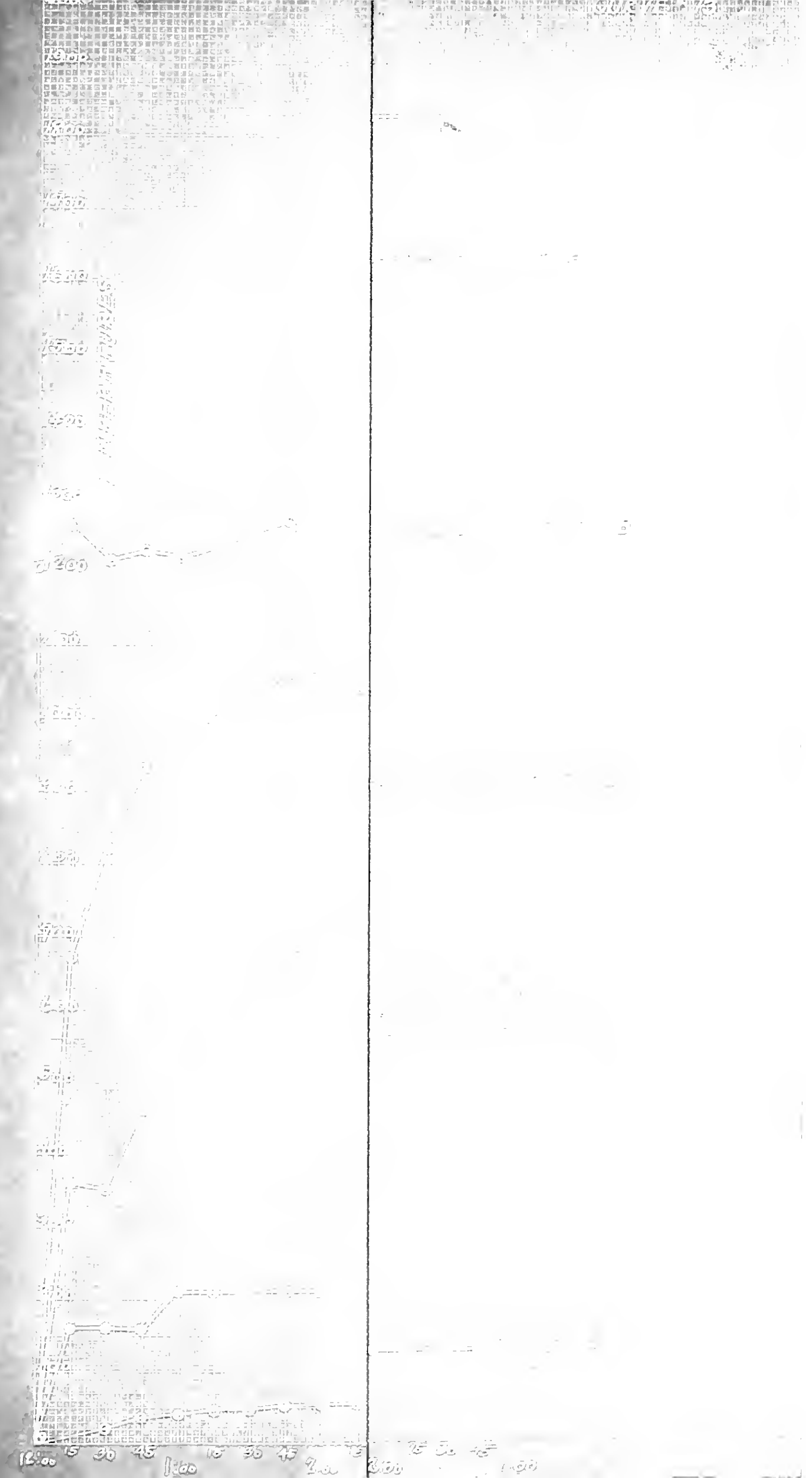



CURVE #8
DIFFERENCE IN TEMPERATURE
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
10
20
30
35
Btu - TEMPERATURE
CURVE

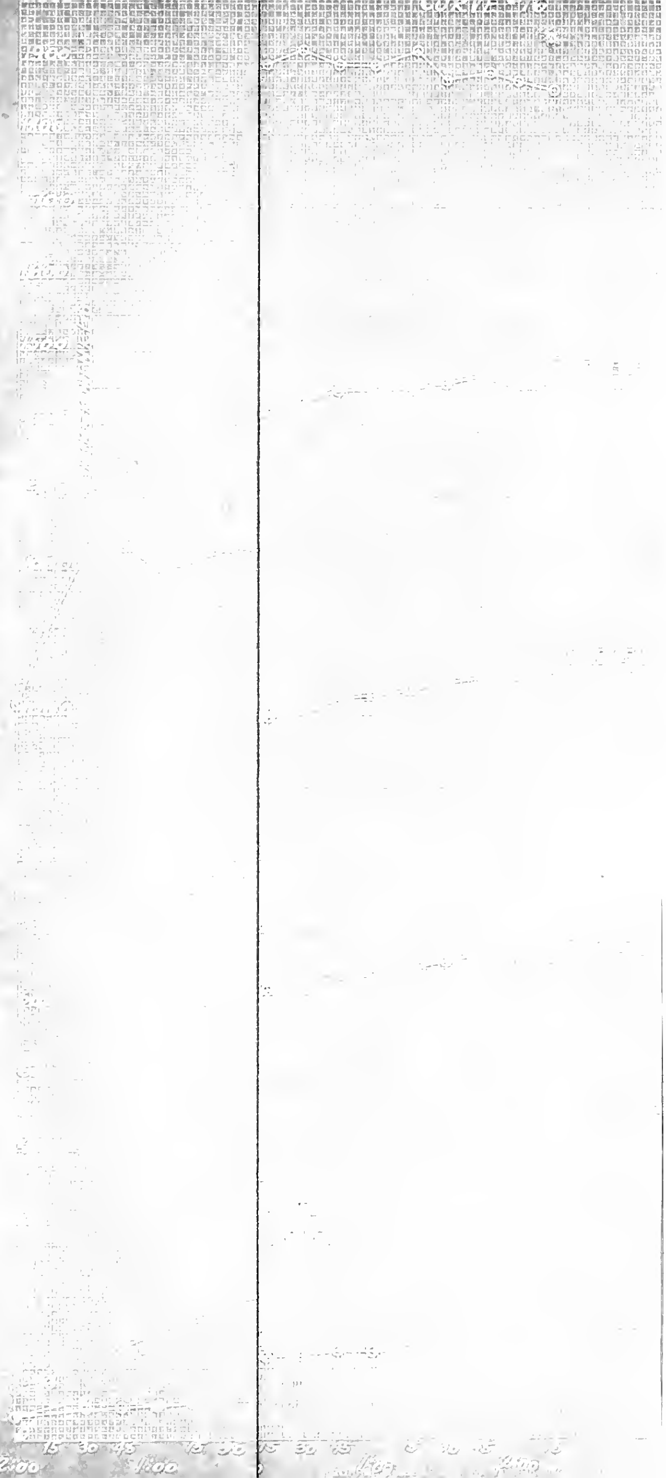

CURVE #9




2000


12:00
15
30
45
1:00
15
30
45

[illegible]


15 30 45
12:00
1:00